SUB E8)

9. An analog, oligomer-based method for determining a mathematical result of carrying out an operation of matrix algebra on input data,

wherein single-stranded oligomers E_i and $\underline{E}_i$ are a subset of all single-stranded oligomers and are each in 1:1 correspondence with the basis vectors $\boldsymbol{e}_i$, i = 1,2,...,m in an abstract m-dimensional vector space;

wherein a set of the oligomers E_i and $\underline{E}_i$ represents an m-component vector $\boldsymbol{V} = \Sigma_i V_i \boldsymbol{e}_i$,

wherein the E_i and $\underline{E}_i$ oligomers have complementary nucleotide sequences, with the E_i oligomers representing the i-th component of $\boldsymbol{V}$ for which the amplitude V_i is positive, and the $\underline{E}_i$ oligomers representing the i-th component of $\boldsymbol{V}$ for which V_i is negative; and

wherein the concentration of each of the oligomers E_i or $\underline{E}_i$ is proportional to the absolute value of the amplitude V_i of the i-th component of $\boldsymbol{V}$,

the method comprising the steps of

(1) obtaining a composition comprising at least one set of single-stranded oligomers E_i and $\underline{E}_i$ representing the components of a vector, wherein the concentrations of the oligomers E_i or $\underline{E}_i$ in the composition are proportional to the absolute values of the amplitudes of the components they represent, which composition represents input data; and

(2) subjecting said composition to at least one physical or chemical treatment having an effect on said oligomers in said composition that is an analog representation of an operation of matrix algebra, and

(3) detecting the effect of said treatment on said oligomers in said composition to determine the analog result of carrying out said operation of matrix algebra on said input data.

10. The method of claim 9, wherein the oligomers independently comprise subunits selected from the group consisting of deoxyribonucleotides, ribonucleotides, and analogs of deoxyribonucleotides or ribonucleotides; and any single oligomer comprises one or a combination of two or more of said different types of subunits.

11. The method of claim 10, wherein said at least one physical or chemical treatment in step (2) is selected from the group consisting of (a) changing the relative concentration of the oligomers in said composition, (b) allowing complementary oligomers in said composition to hybridize to each other, (c) determining the concentration of double-stranded oligomers in the composition, (d) separating double-stranded oligomers from non-double-stranded oligomers in the composition, (e) measuring the rate of hybridization of complementary oligomers in the composition, (f) ligating oligomers together, (g) adding oligomer subunits to an end of an oligomer in an enzyme-catalyzed reaction, (h) using an oligomer as a template in synthesizing a complementary oligomer sequence in a polymerase-catalyzed reaction, (i) ~~modifying~~ phosphorylating or de-phosphorylating a terminus of an oligomer in an enzyme-catalyzed reaction ~~that does not add an additional oligomer subunit~~, and (j) cleaving an oligomer with a restriction enzyme.

12. The method of claim 11 wherein said operation of matrix algebra is multiplication of a vector by a scalar, and

said method comprises changing the total concentration of said oligomers in said composition by a factor equivalent to the scalar by which the vector is multiplied, thereby obtaining an oligomer-containing composition that represents the product of multiplying said vector by said scalar.

13. The method of claim 11 wherein said operation of matrix algebra is addition of vectors, and

said method comprises obtaining, for each vector to be added, a set of single-stranded oligomers E_i and $\underline{E}_i$ representing the components of the vector, wherein the concentrations of the oligomers E_i and $\underline{E}_i$ are proportional to the absolute values of the amplitudes of the components they represent;

mixing together, for each vector to be added, an amount of the set of oligomers representing said vector that is normalized to be proportional to the sum of the absolute values of the amplitudes of the components of said vector;

allowing complementary oligomers in the resulting mixture to hybridize; and

separating the fully hybridized, double-stranded oligomers from the resulting mixture of oligomers, thereby obtaining a set of non-double-stranded oligomers that represents the sum of the added vectors.

14. The method of claim 11 wherein said operation of matrix algebra is determining the inner product of two vectors V_i and W_i, and said method comprises:

(i) obtaining for each vector V_i and W_i, a set of single-stranded oligomers E_i and $\underline{E}_i$ representing the components of the vector, wherein the concentrations of the oligomers E_i and $\underline{E}_i$ are proportional to the absolute values of the amplitudes of the components they represent; and

combining a sample of the oligomers representing vector V_i with a sample of the oligomers representing vector W_i, and measuring both the rate of hybridization R and the concentration of double-stranded oligomers present in the mixture following hybridization;

(ii) obtaining for one of said vectors V_i or W_i an isolated set of single-stranded oligomers $\underline{V}_i$ or $\underline{W}_i$, respectively, that are complementary to the set of oligomers representing said vector V_i or W_i, respectively, wherein the relative concentrations of said complementary oligomers in $\underline{V}_i$ or $\underline{W}_i$ are proportional to the relative concentrations of the oligomers in V_i or W_i, respectively, to which they are complementary, and

combining a sample of said set of complementary oligomers $\underline{V}_i$ or $\underline{W}_i$, with a sample of the other of said vectors, W_i or V_i, respectively and measuring both the rate of hybridization R_+, and the concentration of double-stranded oligomers present in the mixture following hybridization; and

(iii) taking the difference between the values R_+ and R_- after normalizing said values with respect to oligomer concentration, thereby obtaining a numerical value proportional to the inner product of the two vectors.

15. The method of claim 11 wherein said operation of matrix algebra is obtaining the outer product matrix of two vectors V_i for i = ~~1,2~~ 1, 2, ..., m, and W_j for j = 1,2, ..., n, and said method comprises obtaining a set of single-stranded oligomers, each of which comprises (i) a first single-stranded oligomer sequence selected from the group consisting of E_i or $\underline{E}_i$ for each i-th component of ***V*** for i = 1,2, ...m, and (ii) a second single-stranded oligomer sequence selected from the group consisting of E_j or $\underline{E}_j$ for each j-th component of **W** for all j = 1 to j = n,

wherein said resulting set of single-stranded, dimeric oligomers is an analog representation of the matrix formed as the outer product of said two vectors.

16. The method of claim 11 wherein said operation of matrix algebra is obtaining the inner product of a matrix and a vector, and

said method comprises

(a) obtaining a set of single-stranded oligomers representing matrix **T**, wherein each matrix component T_{ij} is represented by single-stranded oligomers comprising a dimeric oligomer sequence selected from the group consisting of 5'-{E_i}{E_j}-3', 5'-{E_i}{$\underline{E}_j$}-3', 5'-{$\underline{E}_i$}{E_j}-3', and 5'-{$\underline{E}_i$}{$\underline{E}_j$}-3', and wherein the concentrations of said dimeric oligomers T_{ij} are proportional to the absolute values of the amplitudes X_i of the matrix components they represent;

(b) obtaining a set of single-stranded oligomers E_i and $\underline{E}_i$ representing the components of a vector **V**, wherein the concentrations of said oligomers E_i and $\underline{E}_i$ are proportional to the absolute values of the amplitudes V_i of the vector components they represent;

(c) obtaining a set of single-stranded oligomers E_i and $\underline{E}_i$ having the sequences of the 5' portions of said dimeric oligomers representing matrix T_{ij} which also comprise in their 3' portions said sequences representing said vector **V**,

wherein the relative concentrations of said oligomers in said set of oligomers having the 5' sequences of said dimeric T_{ij} oligomers are proportional to the relative concentrations of the oligomers in the 3' portions of the corresponding dimeric T_{ij} oligomers having the same sequences as said sequences representing vector **V**;

(d) obtaining a set of single-stranded oligomers E_i and $\underline{E}_i$ complementary to the sequences of the 5' portions of said dimeric oligomers representing matrix T_{ij} which also comprise in their 3' portions E_i or $\underline{E}_i$ sequences complementary to said sequences representing vector **V**,

wherein the relative concentrations of said oligomers in said set of oligomers complementary to the 5' sequences of said dimeric T_{ij} oligomers are proportional to the relative

concentrations of said oligomers in the 3' portions of the corresponding dimeric T_{ij} oligomers that are complementary to said sequences representing vector **V**; and

(e) combining said set of single-stranded oligomers obtained in step (c) with said set of single-stranded oligomers obtained in step (d), to obtain a set of single-stranded oligomers that is an analog representation of the inner product of said matrix **T** and said vector **V**.

17. A method for obtaining a data set V_i^b from an oligomer-based, content-addressable memory following input of a data set U_i^b that represents a portion of V_i^b,

wherein data elements in the form of m-component vectors $V = \Sigma_i V_i \mathbf{e}_i$ are represented in the memory by a set of the oligomers E_i and $\underline{E}_i$ that are a subset of all single-stranded oligomers and are in 1:1 correspondence with the basis vectors $\mathbf{e}_i$ for i = 1,2, ...m in an abstract m-dimensional vector space;

wherein oligomers E_i and $\underline{E}_i$ have complementary nucleotide sequences, with E_i oligomers representing the i-th component of V for which the amplitude V_i is positive, and $\underline{E}_i$ representing the i-th component of V for which V_i is negative; and

wherein the concentration of each of oligomers E_i and $\underline{E}_i$ is proportional to the absolute value of the amplitude V_i of the i-th component of V;

the method comprising:

(a) preparing a content-addressable memory representing memory matrix T_{ij} in which are stored data sets corresponding to vectors V_i^a for a = 1 to a = n, where i = 1,2, ..., m,

comprising obtaining for each vector $\mathbf{V}^a$ a set of single-stranded oligomers, each of which comprises a first single-stranded oligomer sequence selected from the group consisting of E_i or $\underline{E}_i$ for each i-th component of $\mathbf{V}^a$ for i = 1 to i = m, and further comprises a second single-

stranded oligomer sequence selected from the group consisting of E_j or $\underline{E}_j$ for each j-th component of $\mathbf{V}^a$ for j = 1 to j = m, except for i = j; and then pooling said sets of dimeric oligomers obtained for each vector $\mathbf{V}^a$ for a = 1 to a = n thereby forming a set of oligomers representing a content-addressable memory;

(b) combining said pool of dimeric oligomers with a set of oligomers representing partial data set U_i^b under conditions wherein oligomer sequences E_i^b and $\underline{E}_i^b$ of data set U_i^b hybridize specifically to complementary sequences E_j and $\underline{E}_j$ present in said memory pool oligomers; and

obtaining an isolated set of monomeric oligomer strands X_i comprising the oligomer sequences E_i and $\underline{E}_i$ of said memory pool oligomers that hybridized specifically to said U_i^b oligomers, wherein said X_i oligomers do not further comprise said E_j and $\underline{E}_j$ sequences of said memory pool oligomers that are complementary to said U_i^b oligomers;

(c) combining said set of X_i oligomers with a set of single-stranded oligomers comprising a complete, sub-stoichiometric set of E_i and $\underline{E}_i$ so that complementary sequences hybridize to each other, denaturing the resulting duplex molecules, and isolating the subset of X_i oligomer that hybridized specifically to said E_i and $\underline{E}_i$ sequences, to obtain a set of saturated X_i strands, $\mathbf{S}(X_i)$;

(d) repeating steps (b) and (c) iteratively, using the set of saturated X_i strands, $\mathbf{S}(X_i)$ obtained in each previous implementation of step (c) as the set of oligomers representing partial data set U_i^b employed in the subsequent implementation of step (b), to obtain a set of oligomer strands X_i produced by step (b) that represents data set V_i^b.

18. The method of claim 17, wherein the oligomers independently comprise subunits selected from the group consisting of deoxyribonucleotides, ribonucleotides, and analogs of deoxyribonucleotides or ribonucleotides; and any single oligomer comprises one or a

combination of two or more of said different types of subunits.

19. The method of claim 17 wherein each of said oligomers forming said content-addressable memory matrix T_{ij} comprises, in order from the 5' end to the 3' end, (a) an oligomer strand comprising a nucleotide sequence representing an i-th component of *V* selected from the group consisting of E_i and $\underline{E}_i$ for i = 1 to i = m, (b) an oligomer strand comprising a nucleotide sequence representing a j-th component of *V* selected from the group consisting of E_j and $\underline{E}_j$ for j = 1 to j = m, wherein $j \neq i$, and (c) a nucleotide sequence F that is not complementary to any sequence E_i or $\underline{E}_i$ for i = 1 to i = m.

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20. The method of claim 19 wherein said oligomers forming said content-addressable memory T_{ij} are obtained by a method analogous to finding the outer product matrix $\Sigma_a V_i^a V_j^a$ comprising, for each V^a,

(a) obtaining a first set of oligomers E_i and $\underline{E}_i$ for i = 1 to i = m representing data elements to be stored in memory;

(b) obtaining a second set of oligomers E_i and $\underline{E}_i$ for i= 1 to i= m representing data elements to be stored in memory, and comprising at their 3' ends an oligomer sequence F that is not complementary to any sequence E_i or $\underline{E}_i$ for i = 1 to i = m;

(c) combining said first and second sets of oligomers in the presence of ligase so that the 3' ends of said first set of oligomers are ligated to the 5' ends of said second set of oligomers;

(d) removing from the set of ligated oligomers produced in step (c) those oligomers comprising, in the same oligomer, first and second oligomer sequences that are the same sequence, or that are complementary sequences,

and then pooling said sets of dimeric oligomers obtained for each vector $\mathbf{V}^a$ to yield a set of oligomers representing said content-addressable memory matrix T_{ij}.

21. The method of claim 17 wherein said set of oligomer strands X_i is obtained by a method analogous to finding a matrix inner product $\Sigma_j T_{ij} U_i^b$ comprising

C' cont.

(a) obtaining a pool of oligomers forming said content-addressable memory, wherein each oligomer comprises, in order from the 5' end to the 3' end, (i) an oligomer strand comprising a nucleotide sequence representing an i-th component of V selected from the group consisting of E_i and $\underline{E}_i$ for i = 1 to i = m, (ii) an oligomer strand comprising a nucleotide sequence representing a j-th component of V selected from the group consisting of E_j and $\underline{E}_j$ for j = 1 to j = m, wherein $j \neq i$, and (iii) a nucleotide sequence F that is not complementary to any sequence E_i or $\underline{E}_i$ for i = 1 to i = m;

(b) obtaining a set of oligomers U_i representing data vector U_i^b comprising oligomer sequences of the form E_i and $\underline{E}_i$ having concentrations proportional to the corresponding amplitudes in U_i^b;

(c) obtaining a set of oligomers $\underline{U}_i$ comprising oligomer sequences complementary to the oligomer sequences E_i and $\underline{E}_i$ present in U_i, and having concentrations proportional to the corresponding amplitudes of their complements in U_i^b;

(d) ligating to the 5' ends of said oligomers U_i and $\underline{U}_i$ an oligomer strand G that comprises at its 3' end an oligomer sequence complementary to said oligomer sequence F;

(e) combining said oligomers comprising G + $\underline{U}_i$ sequences with a sample of said memory pool oligomers so that oligomers comprising $\underline{U}_i$ sequences complementary to E_j or $\underline{E}_j$ sequences in said memory pool oligomers hybridize thereto and form double-stranded

oligomeric structures comprising a restriction enzyme cleavage site between said E_j or $\underline{E}_j$ sequence and an oligomer comprising an E_i or $\underline{E}_i$ sequence;

cleaving said site with a restriction enzyme; and

isolating the oligomers comprising E_i and $\underline{E}_i$ sequences cleaved from said memory pool oligomers hybridizing to said $G + \underline{U}_i$ oligomers to obtain a set of oligomers $\{X_i\}$ representing the unchanged sign contribution to the inner product;

(f) combining said oligomers comprising $G + U_i$ sequences with a sample of said memory pool oligomers having 3' ends that are modified to inhibit polymerase-catalyzed addition of nucleotides at said 3' ends, so that oligomers comprising U_i sequences complementary to E_j or $\underline{E}_j$ sequences in said memory pool oligomers hybridize thereto and form double-stranded oligomeric structures;

performing polymerase-catalyzed extension of the 3' ends of said hybridized U_i oligomer sequences, using single-stranded E_i and $\underline{E}_i$ sequences extending from said double-stranded structures as template strands, thereby generating oligomer sequences complementary to said E_i and $\underline{E}_i$ sequences attached to the 3' ends of said U_i oligomer sequences;

denaturing the resulting double-stranded oligomeric structures;

isolating said $G + U_i$ oligomers comprising said newly synthesized oligomer sequences complementary to said E_i and $\underline{E}_i$ sequences in said memory pool oligomers;

cleaving oligomers comprising said newly synthesized oligomer sequences complementary to E_i and $\underline{E}_i$ and said $G + U_i$ sequences to separate said newly synthesized oligomer sequences complementary to E_i and $\underline{E}_i$ from said $G + U_i$ sequences;

isolating said oligomers comprising sequences complementary to E_i and $\underline{E}_i$ in said memory pool oligomers to obtain a set of oligomers $\{\underline{X}_i\}$ representing the changed sign

C' cont.

contribution to the inner product; and

(g) combining in an operation analogous to vector addition an amount of said set of oligomers $\{X_i\}$ from step (e) above with an equal amount of said set of oligomers $\{\underline{X}_i\}$ from step (f) above, to yield a set of oligomer strands X_i corresponding to the matrix inner product.

22. The method of claim 17 wherein said single-stranded oligomers comprising a complete, sub-stoichiometric set of E_i and $\underline{E}_i$ of step (c) are anchored to a solid support.

23. The method of claim 22 wherein said solid support is contained in a chromatographic column.

24. The method of claim 24 wherein said solid support is, or is attached to, a silicon or Al_2O_3 chip.

25. A content-addressable memory representing a memory matrix T_{ij} in which are stored data sets corresponding to vectors V_i^a for i = 1 to i = m,

wherein data elements in the form of m-component vectors $\boldsymbol{V} = \Sigma_i V_i \mathbf{e}_i$ are each represented in the memory by a set of the oligomers E_i and $\underline{E}_i$ that are a subset of all single-stranded oligomers and are each in 1:1 correspondence with the basis vectors $\mathbf{e}_i$ for i = 1,2, ...m in an abstract m-dimensional vector space;

wherein oligomers E_i and $\underline{E}_i$ have complementary nucleotide sequences, with E_i oligomers representing the i-th component of $\boldsymbol{V}$ for which the amplitude V_i is positive, and $\underline{E}_i$ representing the i-th component of $\boldsymbol{V}$ for which V_i is negative; and

wherein the concentration of each of oligomers E_i and $\underline{E}_i$ is proportional to the magnitude of the amplitude V_i of the i-th component of ***V***; comprising:

a content-addressable memory representing memory matrix T_{ij} in which are stored data sets corresponding to vectors V_i^a for a = 1 to a = n, where i = 1,2, ..., m,

comprising a pool of dimeric, single-stranded oligomers comprising a set of dimeric oligomers for each vector $\mathbf{V}^a$,

wherein each oligomer in the set of oligomers for each vector $\mathbf{V}^a$ comprises a first single-stranded oligomer sequence selected from the group consisting of E_i or $\underline{E}_i$ for each i-th component of $\mathbf{V}^a$ for i = 1,2, ...m, and further comprises a second single-stranded oligomer sequence selected from the group consisting of E_j or $\underline{E}_j$ for each j-th component of $\mathbf{V}^a$ for all j = 1 to j = m, except for i = j.

26. The content-addressable memory of claim 25, wherein each of said oligomers forming said content-addressable memory comprises, in order from the 5' end to the 3' end, (a) an oligomer strand comprising a nucleotide sequence representing an i-th component of ***V*** selected from the group consisting of E_i and $\underline{E}_i$ for i = 1 to i = m, (b) an oligomer strand comprising a nucleotide sequence representing a j-th component of ***V*** selected from the group consisting of E_j and $\underline{E}_j$ for j = 1 to j = m, wherein $j \neq i$, and (c) a nucleotide sequence F that is not complementary to any sequence E_i or $\underline{E}_i$ for i = 1 to i = m.